A KIC Educational Program
on Climate Sciences for Master Students

Renewable energies

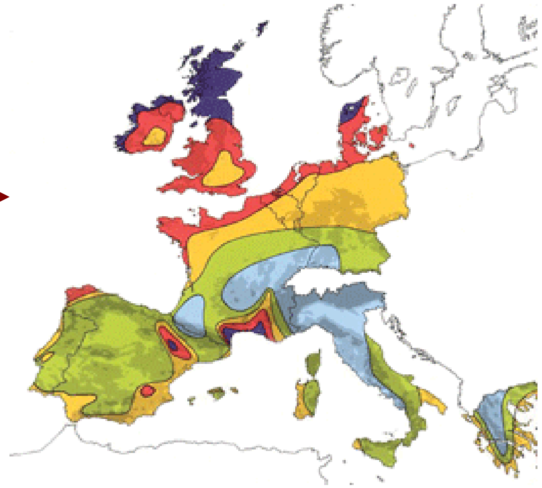
Wind and solar power resource evaluation

7 July 2010

Introduction on WIND energy

Wind Resources

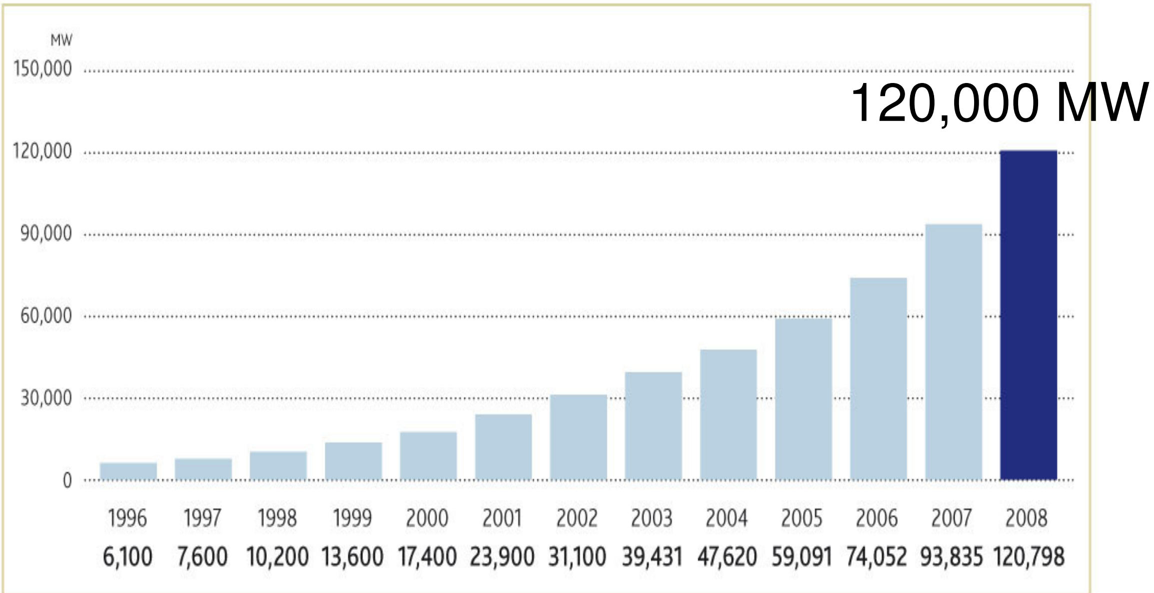
Highest -> Lowest
Purple, red, orange,green, blue



Vertical Axis Turbine

Horizontal Axis Turbine

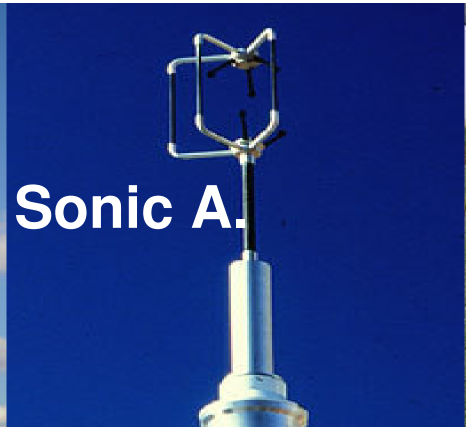
GLOBAL CUMULATIVE INSTALLED CAPACITY 1996-2008



At one geographical location, how can we evaluate the WIND energy?

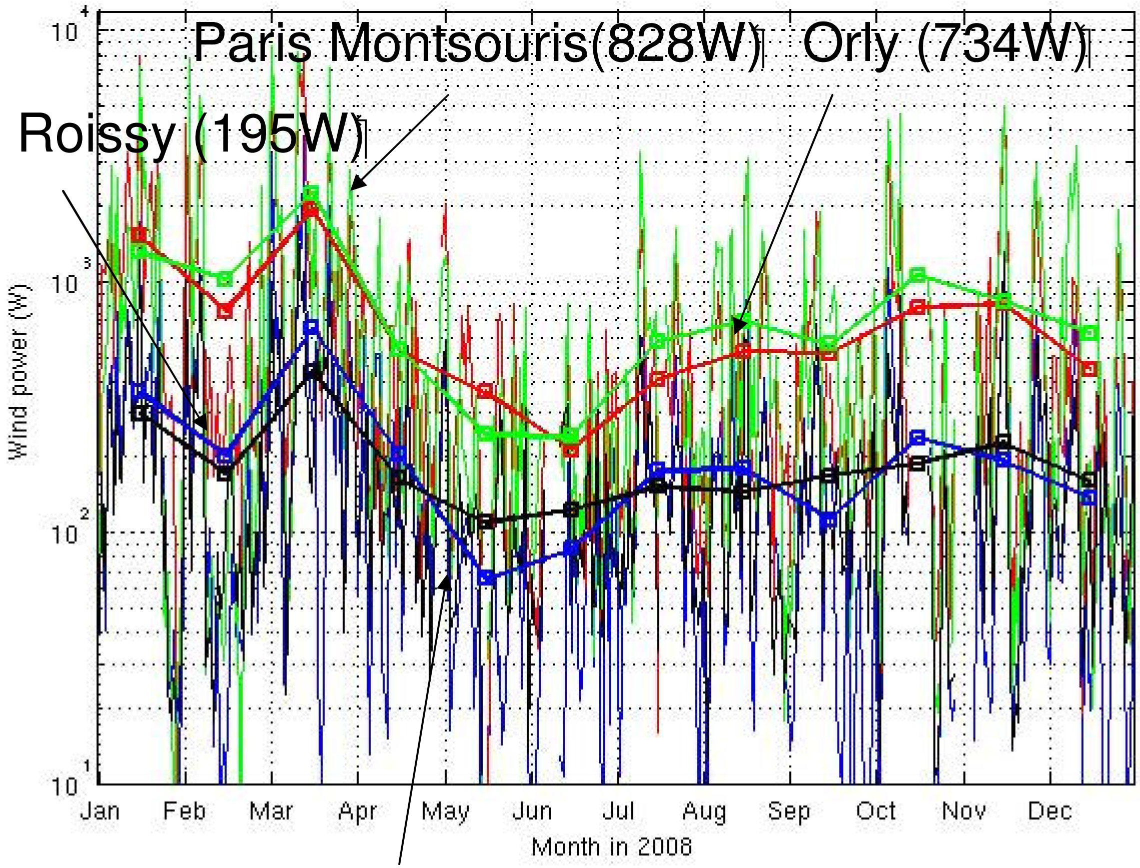
- <u>In situ sensors</u>
  - cup anemometer, sonic anemom.
  - Altitudes (0.5 to 30m)
  - Wind speed (m\s)
  - Wind direction (°)
- + simple,fast, sensitive & accurate
- - low representativeness

- <u>Active remote sensors</u>
  - Wind Lidar, sodar, radar
  - Altitudes (40m up to 2 km)
  - Wind speed (m\s)
  - Wind direction (°)
- + high representativeness
- - complex, costly, low resolution, low signal to noise ratio



What is the order of magnitude of WIND power resource at SIRTA observatory?

Wind power 10 m, 4 sites

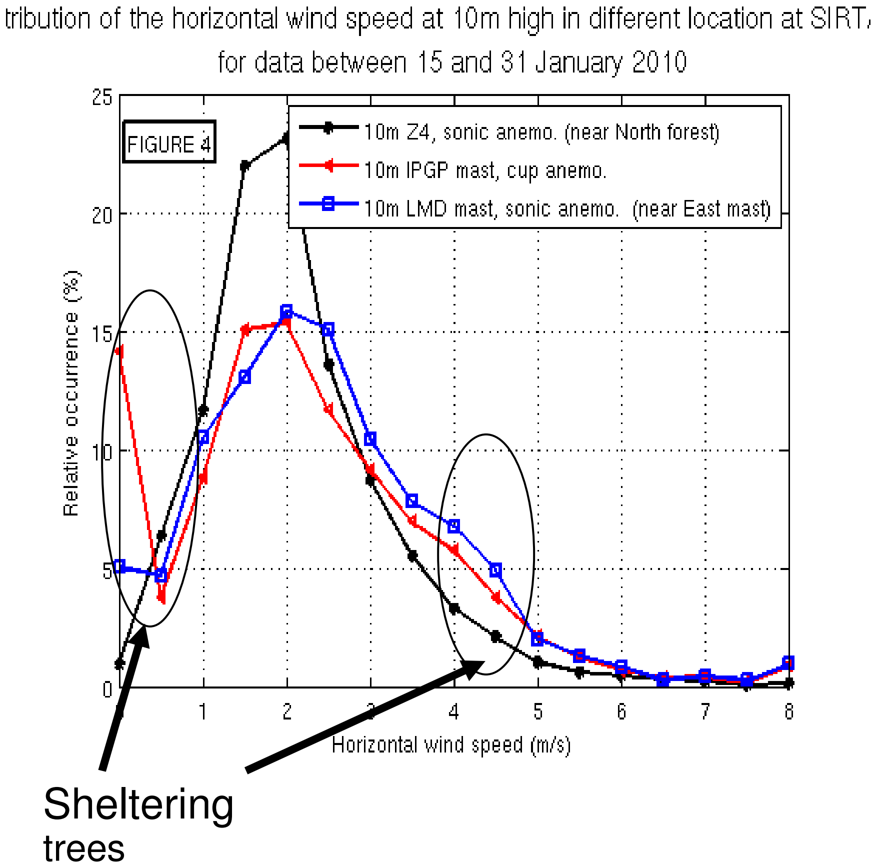


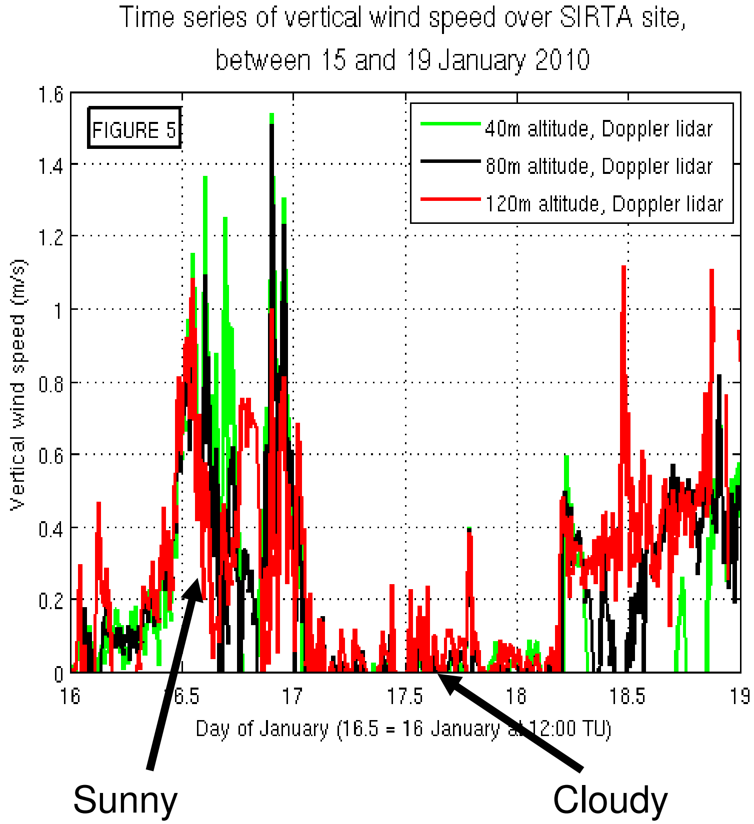
Wind power 4 altitudes, SIRTA site (15 jan-15 feb 2010 mean)

altitude	wind power
60m	98 kW
80 m	233 kW
120 m	810 kW
200 m	4,226 kW

Conclusion :
- 2 good sites (Orly, Paris Montsouris)
- the higher altitude the better but technical problems ?

What parameters alter the WIND energy production?





- Horizontal wind speed depends on surrounding land use and sheltering of the equipment, another important factor is variance within the wind distribution (k coefficient)
- Vertical wind speed is affected by the amount of sunlight and the presence of clouds
- Ratio horizontal vs vertical wind speed is a factor +/- 10

How can we optimize the WIND energy production ?

- Energy pattern

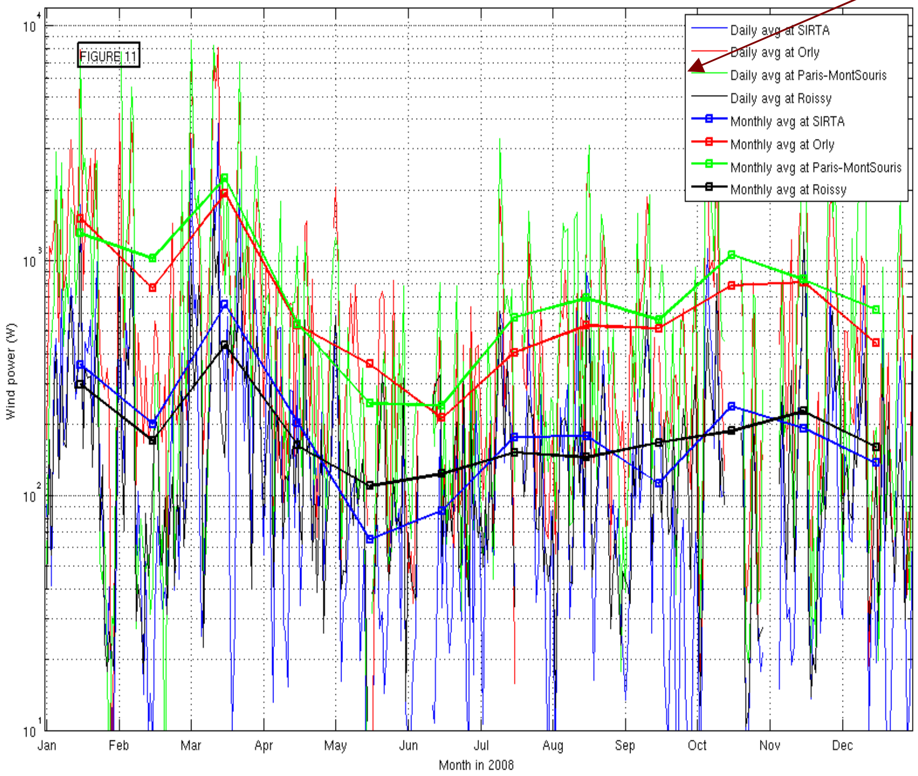
$$K_e = \overline{U^3} / \overline{U}^3$$

- Wind power produced by wind turbine

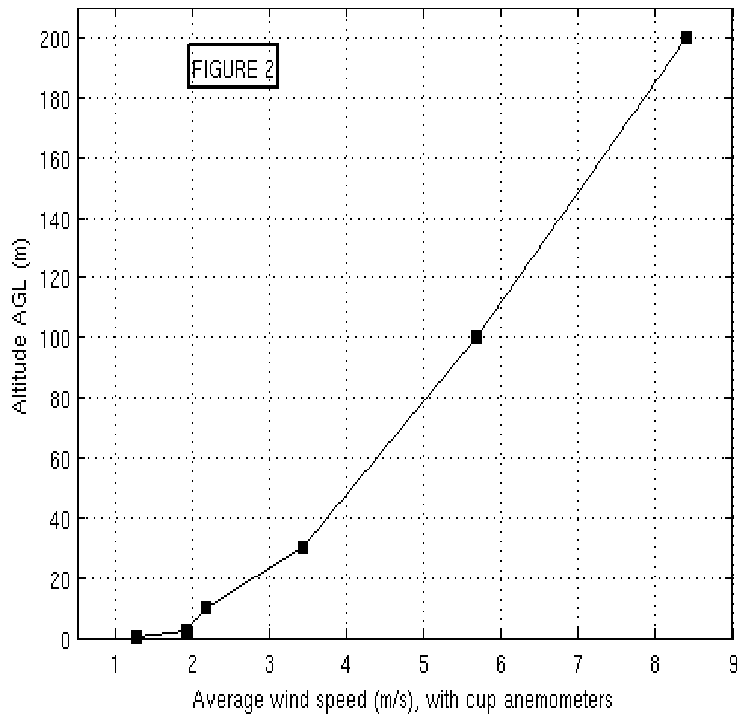
$$\overline{P_w} = (1/2)\overline{\rho} A C_P \overline{U}^3 K_e$$

(C_p is constant)

Annual time series of wind power over SIRTA, Orly, Paris-MontSouris and Roissy sites, daily and monthly average in 2008 at 10m altitude



Vertical distribution of the horizontal wind speed over SIRTA site, average for the period 15-22 January 2010

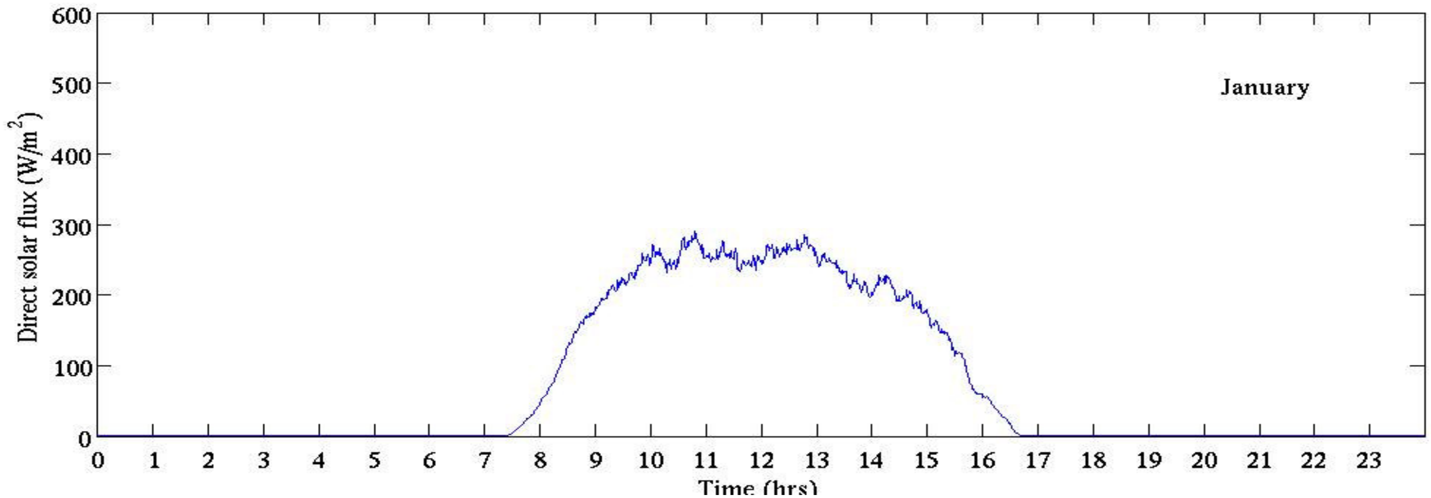


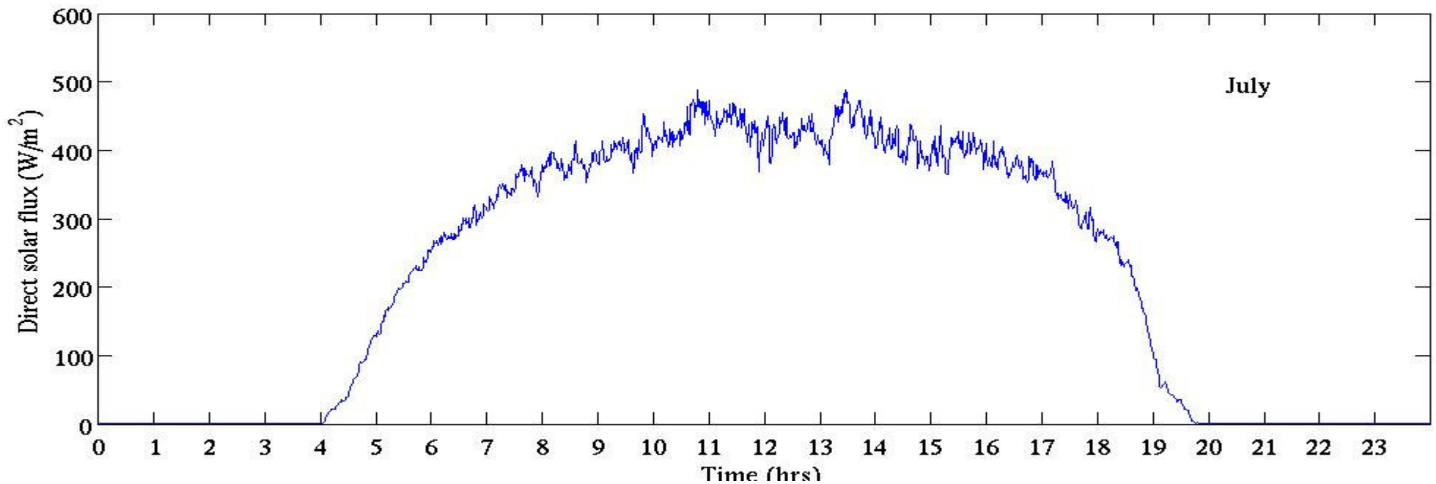
Also... Design Considerations
- Increase Area – length of blades
- Optimize Cp (max 0.6)

Conclusion for the WIND energy

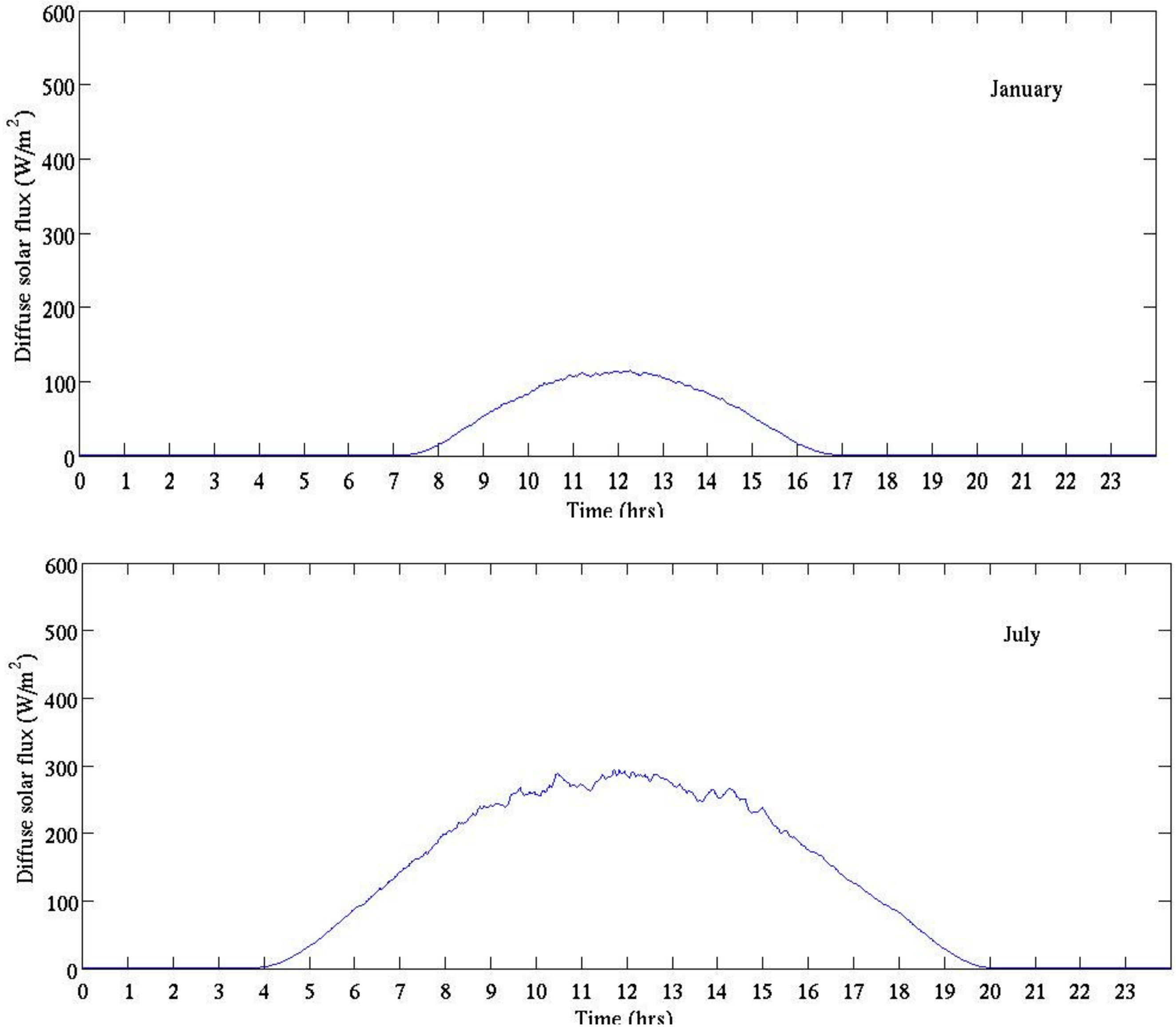
- Measure (speed, direction, variability) with a combination of in situ and remote sensors
- At lower altitudes, Ke is on average higher and has a higher importance for wind energy production. At higher altitudes, Ke is on average low and wind speed is much more decisive.
- Higher altitudes have higher average wind speeds:
  - Build higher windmills
- Choosing best location (more efficient):
  - e.g. offshore windfarms because the surface friction is less in the sea
- Design improvements:
  - Longer blades, greater area, higher Cp

Direct solar flux

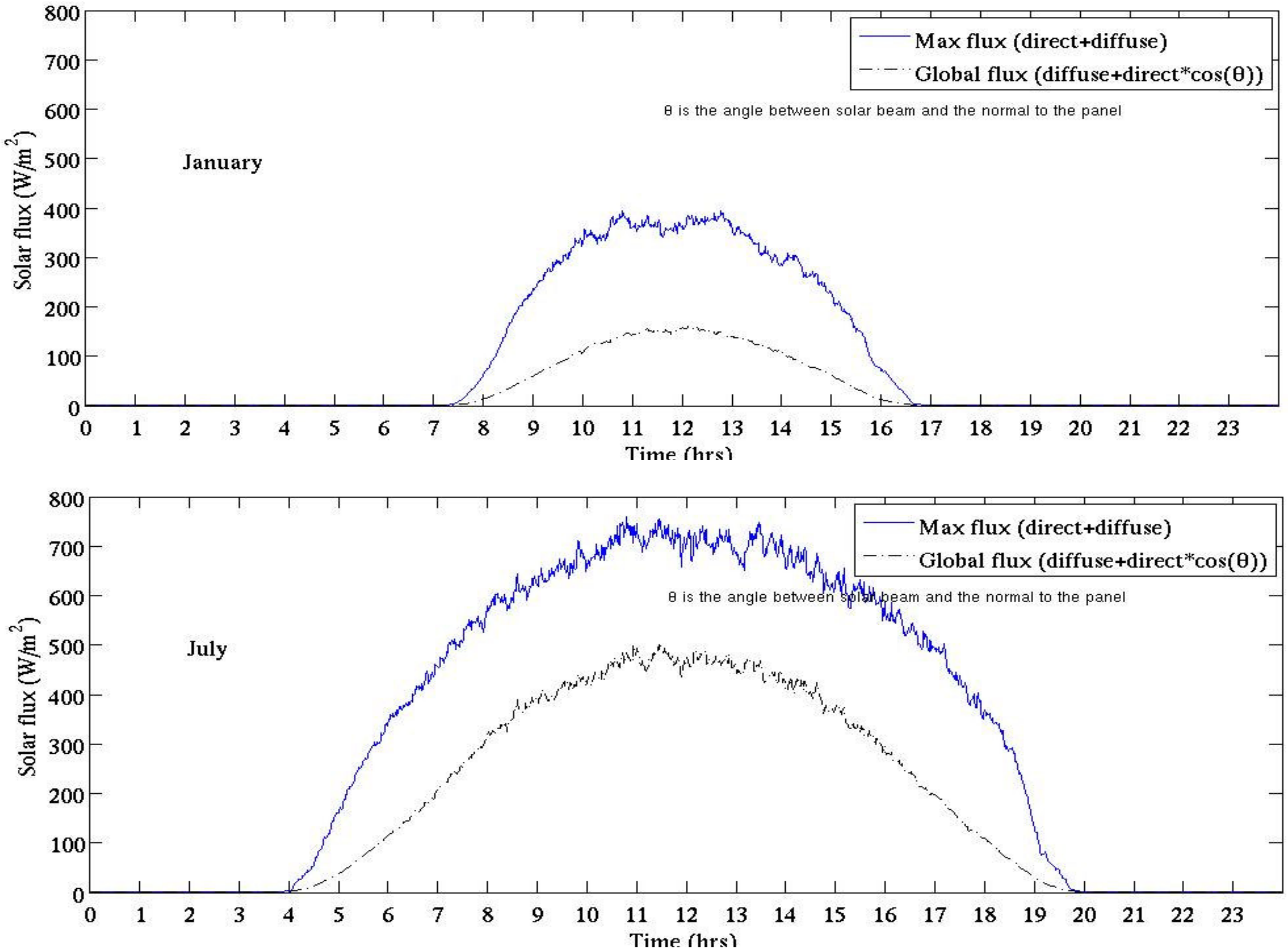




Diffuse solar flux



Global solar flux



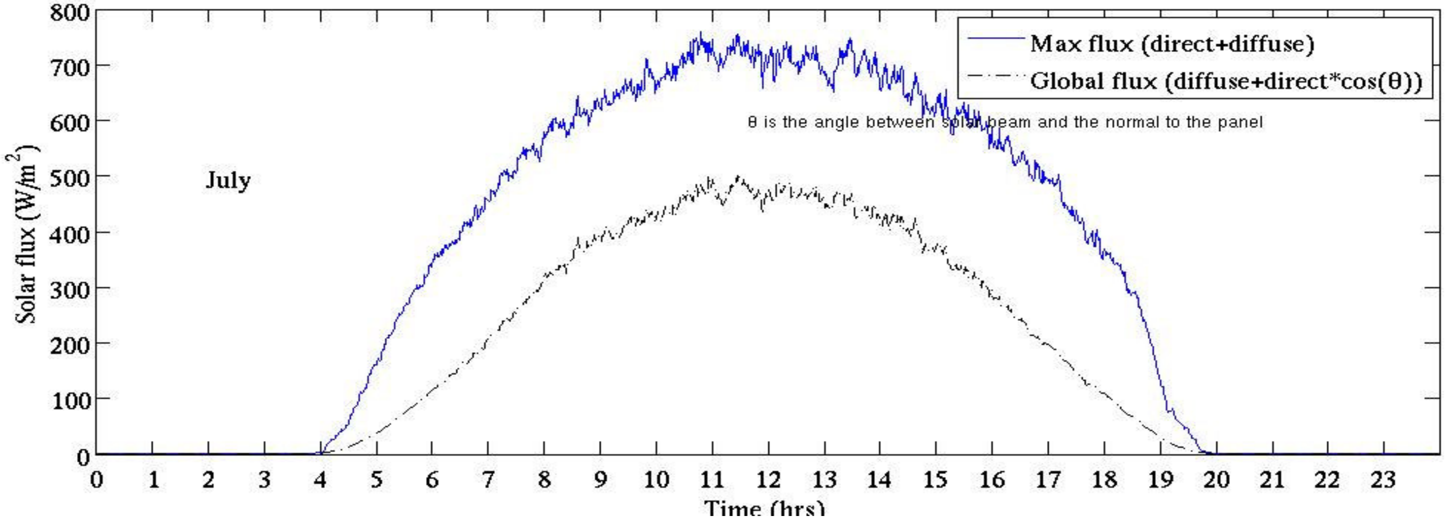
What is the order of magnitude of SOLAR power resource at SIRTA observatory?

Energy coming from the sun today(horizontal): ~970 W/m2 (2.50 pm)

Energy captured by Set-up One (horizontal): ~145 W/m2 = 16%

Energy captured by Set-up Two (inclined): ~160 W/m2

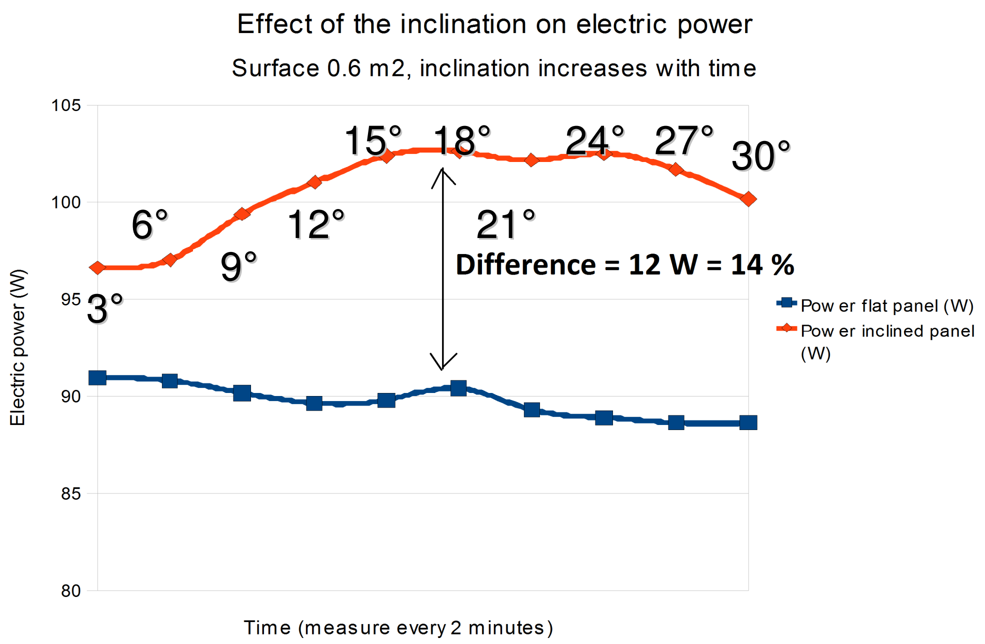
= 18%

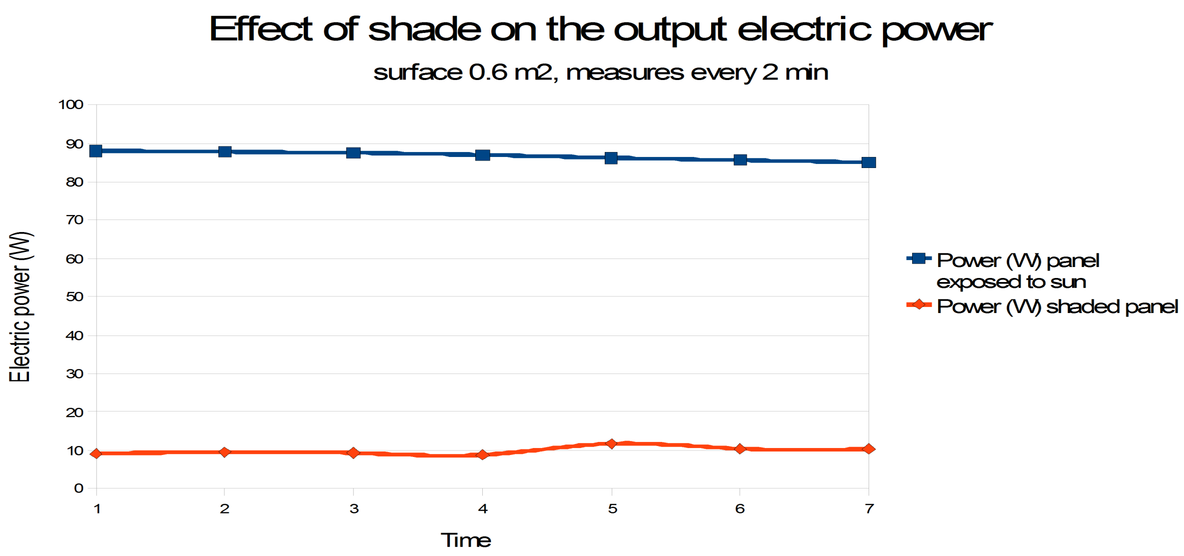


What parameters alter the SOLAR energy production?

- shade / sunlight (e.g. clouds)
- angle of sun to panel (location & time of day)
- diffusion (e.g. aerosols)
- reflection (e.g. white surfaces)

- efficiency of panel





- choose location with long sun days

- sun angle to panel = 0 -> follow the sun

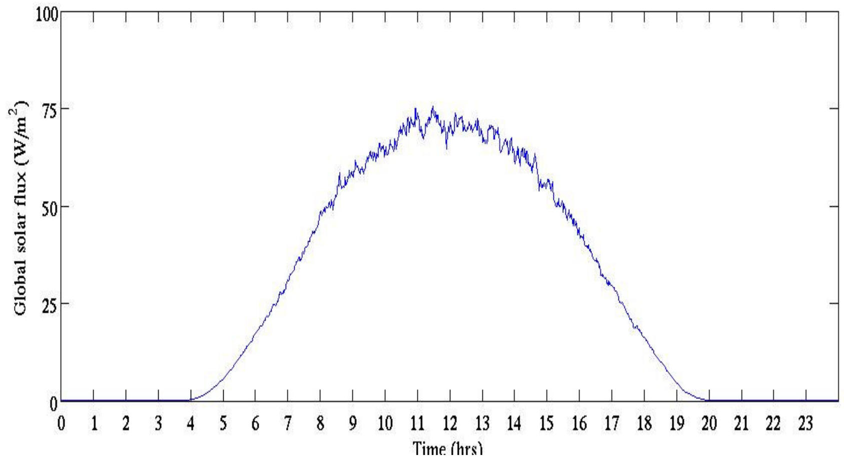
- no clouds / no shade

- reflect sunlight onto panels

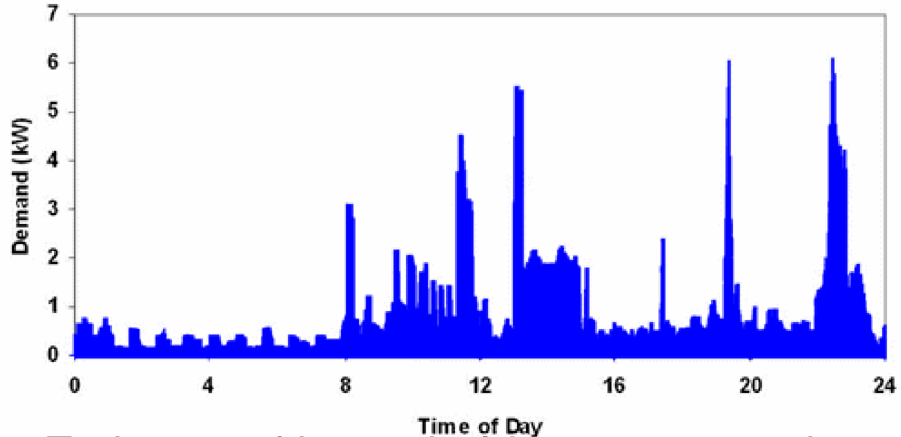
Approximate Calculations:

- 10-20 Mwh per year for one household
- 27-55 kWh per day per household
- 675 Wh/m^2 per day
- 405 Wh/panel per day (0.6 m^2)
- 66-135 panels for one household
  - Note: night-time energy consumption, other factors not taken into account

- 0.15 euros/kWh
- 1500 euros/year



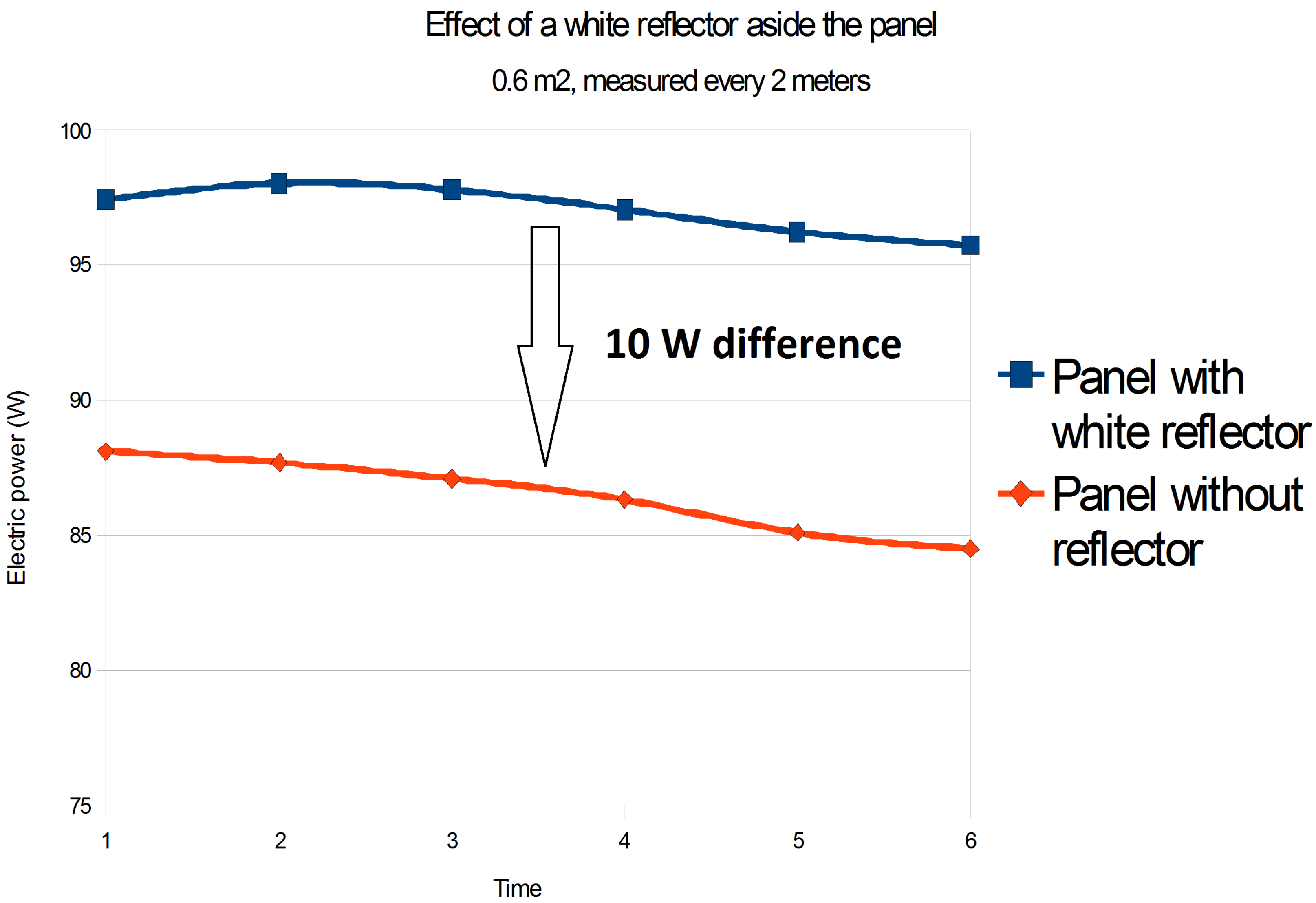
Power captured by solar cell with efficiency of 15% average over month of July



Estimate of household power use taken everyone 2 minutes

Source: The Environmental Change Institute, University of Oxford

How can we optimize the SOLAR energy production ?



SOLAR vision

- improvement of efficiency
- usage of more public and remote space (semi-transparent foil)
- use direct sunlight by moving the panel
- redirecting the sunlight (e.g. through mirrors)
- improvement of electricity transportation and storage technology